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THERMAL PROPERTIES OF MANGOES

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ABSTRACT

*The specific heat, thermal conductivity and thermal diffusivity of mangoes (*Mangifera india, *Anacardiaceae) var.* kaew *having moisture content of 60-80% were measured at high(60-100°C) and low (-10-(-30)°C) temperatures using the modified method of mixture, probe method and the thermal diffusivity tube method,respectively. At high temperatures, the thermal properties increased with both temperature and moisture. Similar effects were found for the specific heat at low temperatures, while the thermal conductivity and thermal diffusivity at low temperatures decreased with an increasing temperature and decreasing moisture. The relationships between thermal properties and temperature and moisture content were found to be polynomial functions.*

INTRODUCTION

Mangoes are economically important fruit in Thailand because they can be processed into a variety of products. Once the thermal properties of mangoes are known, the times and temperatures for various thermal processes can be calculated using theoretical models of heat transfer.[1] In this study the specific heat, thermal conductivity and thermal diffusivity of mangoes were determined and the effects of temperature and moisture content on the thermal properties were evaluated.

There are several methods for measuring the specific heat of food materials. The modified method of mixture[2] is similar to the method of mixture[3] except that the samples and heating medium are not mixed so that any error caused by the heat of solution of soluble matter in the sample is neglected.[3] The differential scanning calorimeter (DSC) is another method which is more precise and less time consuming but is more expensive and requires specific sample preparation.[3]

The methods of measure thermal conductivity can be classified as either steady state or transient methods. The steady state methods most commonly used in foods are the guarded hot plate[4,5] and the concentric cylinder.[6] Steady state methods involve time-independent heat flow generated by a heat source and a heat sink. They require a long equilibration period and are more suitable for low moisture products which will have less moisture loss during measurement. The transient methods subject the sample to time dependent heat flow conditions. They require less time and are more suitable for moist foods.[6] One of the transient heat transfer methods is the Fitch method[7] while the probe method, a modification of the line heat source method, has also been used widely in foods.[1,8,9,10]

Thermal diffusivity can be measured by using either a thermal conductivity probe[3,11] or a thermal diffusivity tube.[12,13,14] The thermal conductivity probe requires less time but more complicated equipment and calculations than the thermal diffusivity tube.

MATERIAL AND METHODS

Sample Preparation

Fresh mangoes (*Mangifera india,* Anacardiaceae) var. *kaew* weighing 240-260 gm with a width of 8 cm and a length of 11 cm and a specific gravity of 1.04-1.05 and moisture content of 79-81% were used. The amount of moisture, protein, fat, fibre and ash were determined using standard methods.[15] The carbohydrate content was calculated by difference. For low moisture (60 and 70 %) samples, fresh mango was cut into 4.5x6.0x2.5 cm and dried at 70°C in a tray dryer to the desired moisture.

The samples for specific heat measurement were cut into 2.0x3.0x2.0 cm and packed in polyethylene bags while those used for thermal conductivity and thermal diffusivity measurement were cut into cylinders with a diameter of 2.54 cm and a height of 2.0 cm. The temperature of samples was adjusted by immersion in a water bath for the high temperature samples or freezer storage for low temperature samples.

Specific Heat Measurement

The specific heat of the samples at high temperature (60, 80 and 100°C) and low temperature (-10, -18 and -30°C) were measured using the modified method of mixture (Fig.1). The temperature changes of the samples were recorded by a temperature recorder (CHINO model DR 015). The specific heat of the samples was calculated by using equation (1) for high temperature samples and equation (2) for low temperature samples. The heat capacity of the calorimeter was determined using water as reference and was calculated using equation (1) and C_{pw} W_{wp} and T_{wp} instead of C_{ps} W_s and T_s.

$$C_{ps}W_sT_s + C_{pw}W_wT_w + H_cT_c = C_{ps}W_sT_F + C_{pw}W_wT_w + H_cT_F - L \qquad (1)$$

$$C_{ps}W_sT_F + C_{pw}W_wT_F + H_cT_F + LH = C_{ps}W_sT_s + C_{pw}W_wT_w + H_cT_c - L \qquad (2)$$

where $L = (C_{pw}W_w + H_c + C_{ps}W_s)(dT/dt)$

Thermal Conductivity Measurement

Thermal conductivity probe used was modified from Sweat[8] using a hypodermic tube with a diameter of 1.25 mm and a length of 33 mm. Details of thermal conductivity probe is shown in Fig. 2. Glycerine (k = 0.285 W/m K at 20°C) was used as a reference to determine the heat supplied to the probe and the temperature changes were also recorded. The thermal conductivity of the samples were calculated using the following equation:

$$k = [\, q/4\pi(T_2 - T_1)]\ \ln(t_2/t_1) \qquad (3)$$

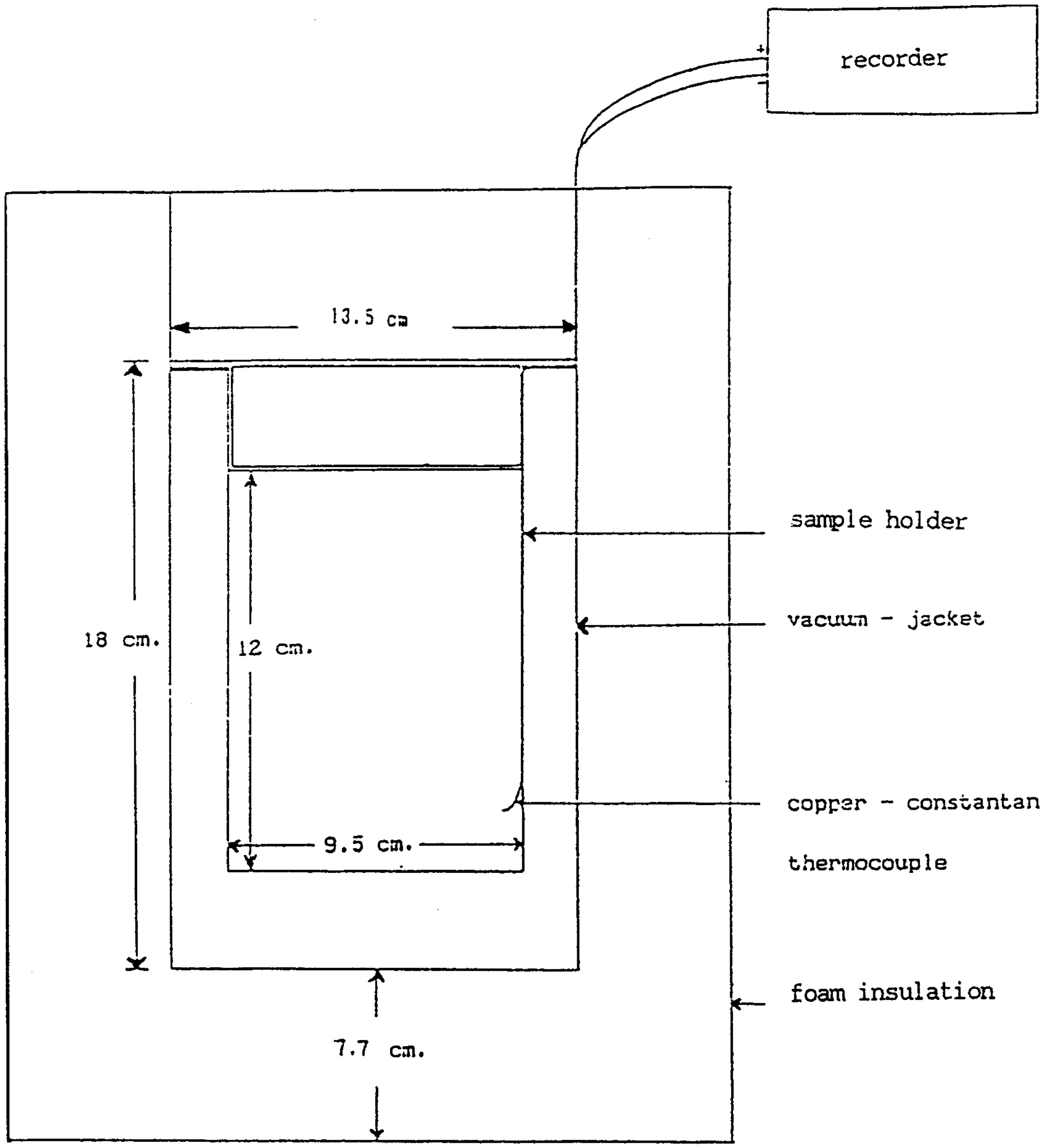

Fig.1. Diagram of calorimeter for specific heat measurement.

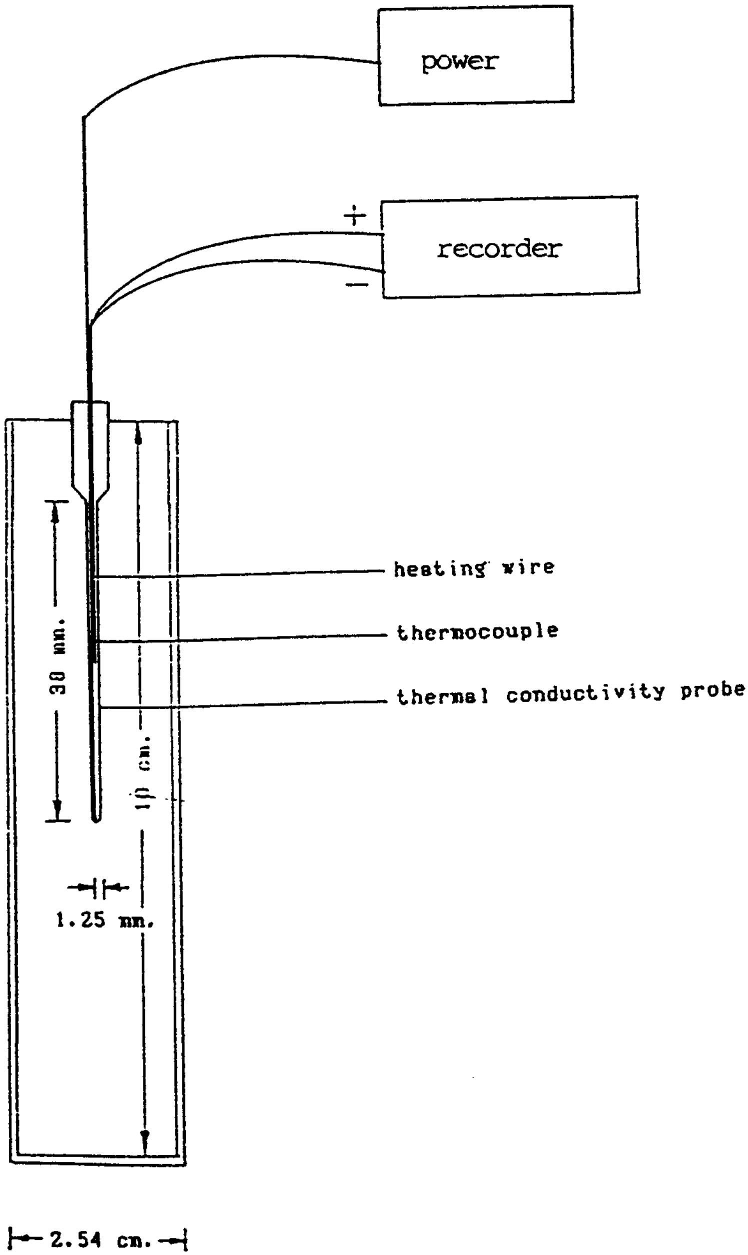

Fig.2. Diagram of thermal conductivity probe.

Thermal Diffusivity Measurement

The thermal diffusivity tube used (Fig. 3) was modified from Dickerson[12]. A stainless steel tube of 2.54 cm diameter, 1.5 mm thickness and 23.0 cm long was used. The cover was a 1.0 mm thick stainless steel sheet with a 2.0 mm rubber seal to avoid leakage. The temperature changes of the sample during experiment were measured using a type T thermocouple and recorded by the same temperature recorder used previously. For high temperatures, a palm oil bath was used while at low temperatures propylene glycol and dry ice were put in the bath. The thermal diffusivity of the sample was calculated using equation (4)

$$\alpha = AR^2/4(T_R - T_o) \quad (4)$$

Statistical Analysis

FLASH CAT (STATISTICAL ANALYSIS PACKAGE : CHULALONGKORN UNIVERSITY, BANGKOK, THAILAND) was used for the analysis of variance (ANOVA) to determine the effects of temperature and moisture content on the thermal properties, while the relationships were obtained from the multiple regression analysis using S.P.S (DATABASIC, Inc. Mt. Pleasant, MI 48858).

RESULTS AND DISCUSSION

Chemical analysis indicated that the major component of the mangoes with an effect on thermal properties was water (Table 1).

TABLE 1 Chemical composition of Mango.

Constituents	% by wt
Moisture	80.58±0.19
Protein	0.63±0.02
Fat	0.12±0.11
Fibre	0.66±0.02
Ash	0.13±0.03
Carbohydrate	17.88

Specific Heat of Mangoes

At both temperature levels, the specific heat was significantly affected (p 0.05) by both temperature and moisture content. The average specific heat of mangoes increased with both temperature and mositure content (Table 2 and 3) due to the high moisture content in the sample. The same results were found in pineapple[16] and apple.[17] The relationship between the specific heat (C_p) and the temperature (T) and moisture content (M) for both high and low temperature levels can be expressed by equations (5) and (6) :

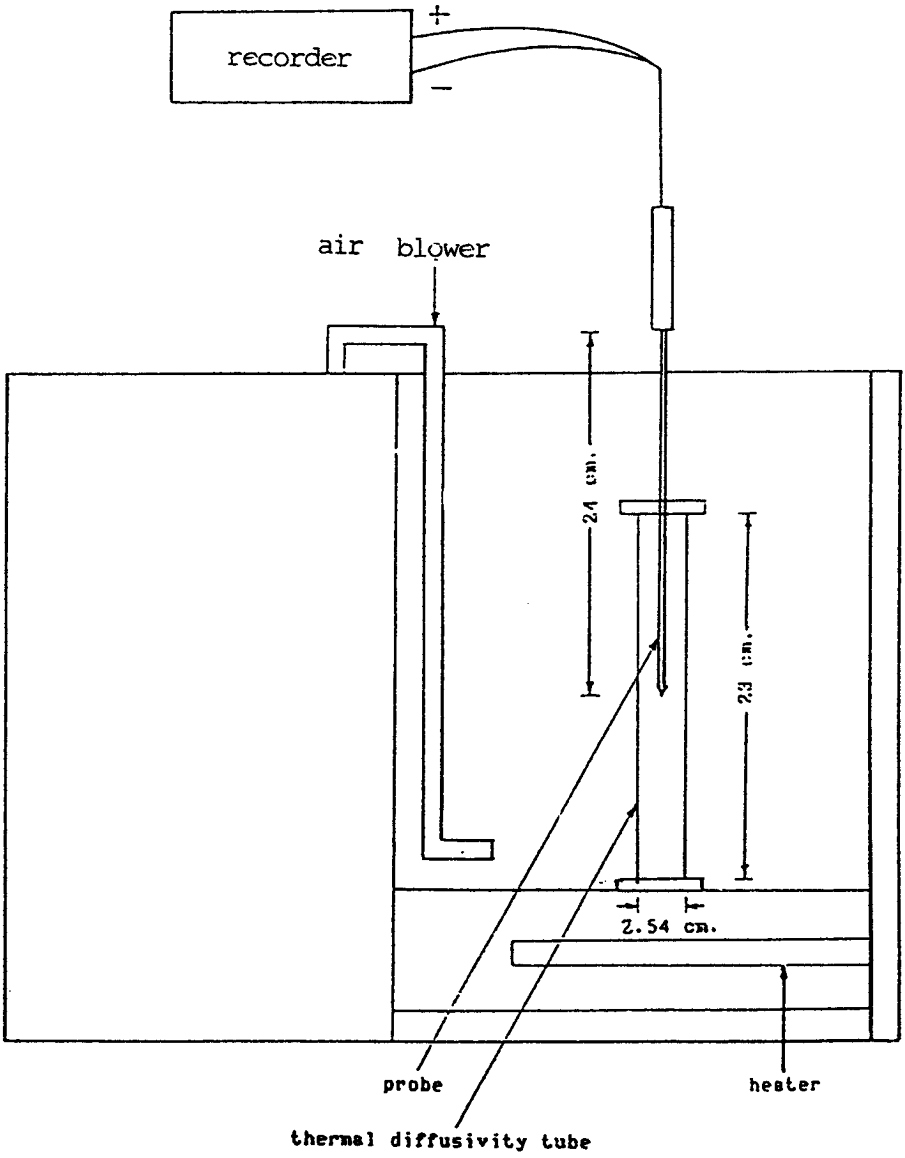

Fig.3. Diagram for the thermal diffusivity measurement.

$$C_p = 0.926 - 4.3 \times 10^{-3}\,T + 1.4 \times 10^{-3}\,M + 3.3\times10^{-5}\,T^2 \quad (R^2=0.905) \qquad (5)$$

$$C_p = 0.350 + 2.0 \times 10^{-3}\,T + 1.9\times10^{-3}\,M \quad (R^2=0.700) \qquad (6)$$

The average specific heat of mangoes at high temperatures ranged from 0.873-0.936 cal/gm°C while those at low temperatures were 0.411-0.485 cal/gm°C as the ice has a lower specific heat than water does.[3]

TABLE 2 Specific heat of mangoes at high temperatures and different moisture content.

Moisture	**Specific heat * ±S.D. (cal/g°C) at temperature**		
Content (%)	**60-65°C**	**80-85°C**	**95-100°C**
59-61	$0.873\pm0.005^{A,a}$	$0.886\pm0.011^{A,a}$	$0.912\pm0.008^{B,a}$
69-71	$0.890\pm0.008^{A,b}$	$0.902\pm0.005^{A,b}$	$0.924\pm0.009^{B,a}$
79-81	$0.908\pm0.009^{A,c}$	$0.915\pm0.005^{A,b}$	$0.936\pm0.004^{B,a}$

* - The mean values with the same capital letters are not significantly different at the same moisture content.
- The mean values with the same letters are not significantly different at the same temperature.

TABLE 3 Specific heat of mangoes at low temperatures and different moisture content.

Moisture	**Specific heat * ±S.D. (cal/g°C) at temperature**		
Content (%)	**-30±1°C**	**-18±1°C**	**-10±1°C**
59-61	$0.411\pm0.014^{A,a}$	$0.422\pm0.010^{A,a}$	$0.441\pm0.003^{B,a}$
69-71	$0.426\pm0.025^{A,a}$	$0.446\pm0.018^{A,ab}$	$0.465\pm0.010^{A,b}$
79-81	$0.434\pm0.033^{A,a}$	$0.470\pm0.014^{A,b}$	$0.485\pm0.006^{A,c}$

* - The mean values with the same capital letters are not significantly different at the same moisture content.
- The mean values with the same letters are not significantly different at the same temperature.

Thermal Conductivity of Mangoes

The thermal conductivity of mangoes increased with both temperature and moisture content for high temperatures (Table 4). This is consistent with the results of powdered milk[18] and apples.[9] The relationship between the thermal conductivity (k) and the temperature and moisture content was :

$$k = 0.459 - 7.2\times10^{-3}\,T - 2.5\times10^{-3}\,M + 1.7\times10^{-4}\,TM \quad (R^2=0.823) \qquad (7)$$

At low temperatures, the thermal conductivity of mangoes increased as temperature decreased (Table 5) similarly to that of chicken.[19] At each temperature, the thermal conductivity increased with increasing moisture content (Table 5) due to the high thermal conductivity of water. The thermal conductivity was affected by both temperature and moisture content and could be described by the following equation :

$$k = 0.099 + 9.0\times10^{-3}T + 0.010M + 4.9\times10^{-4}\,T^2 \quad (R^2 = 0.908) \qquad (8)$$

The average thermal conductivity at high temperatures was lower than those at low temperatures due to the higher thermal conductivity of the ice.

TABLE 4 Thermal conductivity of mangoes at high temperatures and different moisture content.

Moisture Content (%)	Thermal conductivity * ±S.D. (W/m.K) at temperature 60-65°C	80-85°C	95-100°C
59-61	0.507±0.024^{A,a}	0.533±0.032^{A,a}	0.569±0.031^{A,a}
69-71	0.550±0.026^{A,a}	0.674±0.071^{AB,b}	0.803±0.079^{B,b}
79-81	0.675±0.054^{A,b}	0.726±0.022^{A,b}	0.855±0.052^{B,b}

* - The mean values with the same capital letters are not significantly different at the same moisture content.

- The mean values with the same letters are not significantly different at the same temperature.

TABLE 5 Thermal conductivity of mangoes at low temperatures and differrent moisture content.

Moisture Content (%)	Thermal conductivity * ±S.D. (W/m.K) at temperature -30±1°C	-18±1°C	-10±1°C
59-61	$0.906 \pm 0.035^{A,a}$	$0.715 \pm 0.035^{B,a}$	$0.677 \pm 0.044^{B,a}$
69-71	$0.951 \pm 0.060^{A,a}$	$0.802 \pm 0.018^{B,b}$	$0.793 \pm 0.042^{B,b}$
79-81	$1.134 \pm 0.008^{A,b}$	$0.925 \pm 0.041^{B,c}$	$0.860 \pm 0.062^{B,b}$

* - The mean values with the same capital letters are not significantly different at the same moisture content.

- The mean values with the same letters are not significantly different at the same temperature.

Thermal Diffusivity of Mangoes

The thermal diffusivity was significantly affected (p 0.05) by temperature, moisture content and the interaction of temperature and moisture content at both temperature levels. At high temperatures, the thermal diffusivity increased as the temperature and moisture content increased (Table 6). The similar results were obtained for mango (var.rad)[20] and powdered milk.[21] The relationship between the thermal diffusivity and the temperature and moisture content was :

$$\alpha \times 10^7 = 3.921 - 0.058T - 0.024M + 4.7\times10^{-4}TM + 2.1\times10^{-4}T^2 \ (R^2 = 0.943) \quad (9)$$

At low temperatures, the thermal diffusivity decreased with increasing temperature similarly to that of cod minces[22] (Table 7). The thermal diffusivity at constant temperature increased as the moisture content increased (Table 7). The effect of temperature and moisture content on the thermal diffusivity could be explained by the equation (10) :

$$\alpha \times 10^7 = 0.026 - 0.232T + 0.041M - 1.3\times10^{-4}\, TM - 5.3\times10^{-3}\, T^2 \ (R^2 = 0.932) \quad (10)$$

TABLE 6 Thermal diffusivity of mangoes at high temperatures and different moisture content.

Moisture Content (%)	Thermal diffusivity * ± S.D.(m2 /S)x 10^7 at temperature 60-65°C	80-85°C	95-100°C
59-61	$1.433 \pm 0.015^{A,a}$	$1.492 \pm 0.020^{A,a}$	$1.576 \pm 0.053^{B,a}$
69-71	$1.502 \pm 0.028^{A,b}$	$1.606 \pm 0.067^{A,b}$	$1.784 \pm 0.067^{B,b}$
79-81	$1.584 \pm 0.025^{A,c}$	$1.750 \pm 0.055^{B,c}$	$2.052 \pm 0.083^{C,c}$

* - The mean values with the same capital letters are not significantly different at the same moisture content.

- The mean values with the same letters are not significantly different at the same temperature.

TABLE 7 Thermal diffusivity of mangoes at low temperatures and different moisture content.

Moisture Content (%)	Thermal diffusivity * ± S.D.(m2 /S)x 10^7 at temperature -30-(-13)°C	-18-(-6)°C	-10-(-2)°C
59-61	$5.246 \pm 0.109^{A,a}$	$4.649 \pm 0.120^{B,a}$	$3.904 \pm 0.696^{C,a}$
69-71	$5.612 \pm 0.110^{A,b}$	$4.765 \pm 0.081^{B,a}$	$4.034 \pm 0.208^{C,a}$
79-81	$6.033 \pm 0.111^{A,c}$	$5.758 \pm 0.017^{B,b}$	$4.527 \pm 0.119^{C,b}$

* - The mean values with the same capital letters are not significantly different at the same moisture content.

- The mean values with the same letters are not significantly different at the same temperature.

CONCLUSIONS

At high temperatures (60-100°C), the effects of temperature and moisture content on the thermal properties of mangoes could be described by the following equations :

$$C_p = 0.926 - 4.3\times10^{-3}\,T + 1.4\times10^{-3}\,M + 3.3\times10^{-5}\,T^2$$

$$k = 0.459 - 7.2\times10^{-3}\,T - 2.5\times10^{-3}\,M + 1.7\times10^{-4}\,TM$$

$$\alpha \times 10^7 = 3.921 - 0.058T - 0.024M + 4.7\times10^{-4}\,TM + 2.1\times10^{-4}\,T^2$$

At low temperatures (-30-(-10)°C), similar relationships between the thermal properties of mangoes and temperature and moisture content were found to be :

$$C_p = 0.350 + 2.0\times10^{-3}\,T + 1.9\times10^{-3}\,M$$
$$k = 0.099 + 9.0\times10^{-3}\,T + 0.010M + 4.9\times10^{-4}\,T^2$$
$$\alpha \times 10^7 = 0.026 - 0.232T + 0.041M - 1.3\times10^{-4}\,TM - 5.3\times10^{-3}\,T^2$$

NOMENCLATURE

A = rate of temperature increase of the medium.
C_p = specific heat ; cal/g°C
H_c = heat capacity of calorimeter ; cal/°C
k = thermal conductivity ; W/m.K
L = heat loss to or gain from the surrounding ; cal
LH = latent heat of fusion of ice in sample ; cal
M = moisture content; %
q = heat supplied per unit length of thermal conductivity probe ; W/m
R = internal radius of thermal diffusivity tube ; m
T = temperature; °C
t = time ; min
W = weight ; g
α = thermal diffusivity ; m^2/s

subscript

c = calorimeter
F = equilibrium point
o = center of sample
R = outside wall
s = sample
w = water
wp = water in polyethylene bag.

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บทคัดย่อ

จากการหาค่าความร้อนจำเพาะ สภาพนำความร้อน และสภาพแพร่ความร้อนของมะม่วง (*Mangifera india*, Anacardiaceae) **พันธุ์แก้วซึ่งมีความชื้น** (60-80%) **ที่อุณหภูมิสูง** (60-100 **องศาเซลเซียส) และอุณหภูมิต่ำ** (-10 - (-30) **องศาเซลเซียส) โดย** modified method of mixture, probe method **และ** thermal diffusivity tube method **พบว่าที่อุณหภูมิสูง สมบัติทางความร้อนมีค่าสูงขึ้นเมื่ออุณหภูมิและความชื้นเพิ่มขึ้น ค่าความร้อนจำเพาะที่อุณหภูมิต่ำมีค่าสูงขึ้นเมื่ออุณหภูมิและความชื้นเพิ่มขึ้นเช่นเดียวกัน แต่ค่าสภาพนำความร้อนและสภาพแพร่ความร้อนที่อุณหภูมิต่ำจะลดลงเมื่ออุณหภูมิเพิ่มขึ้นและความชื้นลดลง ความสัมพันธ์ระหว่างค่าสมบัติทางความร้อนกับอุณหภูมิและความชื้นเป็นพหุนามฟังก์ชัน**